Arnold Schwarzenegger
Governor

UNDERSTANDING ENTRAINMENT AT COASTAL POWER PLANTS: RESULTS FROM THE W.I.S.E.R. PROGRAM FOR STUDYING IMPACTS AND THEIR REDUCTION

PIER FINAL PROJECT REPORT

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Prepared By:
Moss Landing Marine Labs

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Prepared By:
Moss Landing Marine Laboratories
Lara Ferry
Moss Landing, CA 95039-9647
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Prepared For:
Public Interest Energy Research (PIER)
California Energy Commission

Joseph O'Hagan
Contract Manager

Linda Spiegel
Program Area Lead
Energy-Related Environmental Research

Kenneth Koyama
Office Manager
Energy Generation Research Office

Laurie ten Hope, Ph.D.
Deputy Director
ENERGY RESEARCH and DEVELOPMENT DIVISION

Melissa Jones
Executive Director

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

- PIER funding efforts are focused on the following RD&D program areas:
- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Understanding Entrainment at Coastal Power Plants: Informing a Program to Study Impacts and Their Reduction is the final staff report for the Environmental Effects of Cooling Water Intake Structures project (contract number 500-04-025) conducted by Moss Landing Marine Laboratories. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

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Abstract

A significant portion of California's electricity generation capacity, approximately 45 percent, is represented by power plants located along the state's coast and estuaries that use once-through cooling technology, where the ocean water is passed by the condenser and then discharged back into a water body. This cooling technology uses about 17 billion gallons of seawater per day when all such power plants are operating. Carried along in these water flows are millions of small aquatic organisms that are killed as they pass through the power plant, an impact known as entrainment. Although some of these facilities have been operating since the 1950s, a scientific understanding of the ecological effects of the use of once-through cooling is quite limited. To address this, the California Energy Commission funded research to understand and provide tools to minimize the effects of once-through cooling on California coastal resources. This research was funded under the umbrella of the Water Intake Systems Environmental Research or WISER Program. Research projects were selected for funding by: 1) conducting a literature review of the effects of once-through cooling; 2) identifying areas where knowledge gaps exist(ed) through a public workshop; and 3) bringing together an advisory group to conduct a request for proposals, review submitted proposals, and select researchers to conduct the studies meant to fill knowledge gaps. The areas of research that were funded focused on the ability to: measure entrainment effects, determine the affected area and related oceanography, identify entrained species, and determine when mitigation is useful or successful. An overview of each of the specific research questions is summarized in this report. During the course of the four-year contract, the regulatory climate changed significantly with the results of the Riverkeeper II lawsuit and the decision by the U.S. Environmental Protection Agency to subsequently suspend Phase II of the Clean Water Act Section 316(b) and issued a memo stating that best professional judgment should be used regarding cooling water intake and limiting ecological impact. The results of WISER research remain pertinent for determining best professional judgment and for informing state decision-making regarding permitting of once-through cooling facilities. The primary mission of the work summarized here was to determine the best methodology to completely and accurately measure any ecological impacts, primarily of organism entrainment. Secondarily, methods of reducing potential impacts are also explored.

Keywords: Once-through cooling, marine, coastal, estuary, entrainment, impingement, intake screen, entrainment research, power plant

Executive Summary

Introduction

Approximately 45 percent of the California power plants located along the state's coast and estuaries use once-through cooling technology. Collectively, these facilities are permitted to draw approximately17 billion gallons of seawater per day to cool the condensers (although they draw less water when they are not operating at full capacity). Water is brought into the plant, passed by the condenser once to remove waste heat, and then discharged. The biological impacts from cooling water withdrawals are characterized as *entrainment* (where small aquatic organisms are carried by the cooling water into the power plant and assumed to be killed by heat, turbulence, and/or chemicals) and as *impingement* (where the cooling water intake traps larger organisms against the intake screens). Thermal effects occur when discharged cooling water is hotter than the temperatures of the receiving water body. Withdrawal of cooling water from California waters potentially harms millions of aquatic organisms each year, including fish, fish larvae and eggs, crustaceans, shellfish, sea turtles, and marine mammals. The largest impacts are likely to come from the removal of early life stages of fish and shellfish. Although many of the facilities have been operating since the 1950s, there are still knowledge gaps about how to accurately measure, reduce, and mitigate the impacts to the ecosystem.

To address these knowledge gaps, the California Energy Commission funded research to understand and provide tools to more accurately measure the effects of once-through cooling on California coastal resources. This research was funded under the umbrella of the Water Intake Systems Environmental Research (WISER) Program housed at the Moss Landing Marine Laboratories of the California State University system through a contract to develop a scientific framework for assessing possible short and long-term ecological impacts of once-through cooling on coastal and estuarine ecosystems. Understanding how water intakes affect sensitive species and aquatic communities will allow plant operators and regulatory agencies to effectively manage and mitigate such cooling water withdrawals for maximal economic and environmental benefits. Specifically, this contract was to identify research priorities for determining the ecological effects of once-through cooling technology on aquatic ecosystems and the effectiveness of potential mitigation measures.

Shortly after the inception of this contract, the United States Environmental Protection Agency issued a new rule (Phase II) under the Clean Water Act Section 316(b) requiring the reduction of entrainment and impingement effects from cooling water intakes. As part of the process of quantifying those impacts and implementing measures for their reduction, operators were developing sampling plans and monitoring. Such information was required before issuance of National Pollutant Discharge Elimination System permits. Based upon a federal court ruling in early 2007, the United States Environmental Protection Agency officially suspended the rule that year and issued a memo stating that best professional judgment will be the standard until a new rule is adopted. The California Energy Commission, however, requires a license before construction or operation of a new thermal power plant 50 megawatts (MW) or larger and when an operator upgrades or repowers a facility adding 50 MW. The Energy Commission can require monitoring and mitigation as part of its licensing process. For such decisions to be effective, it is required that rulings and other actions consider the larger biological and ecological ecosystems in which the plants operate. The research summarized here provides the most current and effective tools available for determining the ecosystem level impacts.

The State Water Resources Control Board has adopted a *Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling* that establishes technology-based standards for implementing Clean Water Act section 316(b) within the state. The aim of these standards is to reduce the effects of cooling water intake structures on marine and estuarine life. The research summarized here will be useful as a methodological basis for determining on-going impacts to the ecological community and possibly reducing or mitigating those impacts.

Purpose

This report summarizes research regarding methods for determining and possibly reducing or mitigating the impacts of once-through cooling under the Water Intake Systems Environmental Research (WISER) program. Each of the principal investigators addressed one or more of the specific knowledge gaps identified in the program workshop held in April 2006. These knowledge gaps were specifically identified as the ability to: directly measure effects, determine the affected area and related oceanography, identify entrained species, determine useful technology to implement for reducing entrainment, and determine when mitigation is useful or successful, and are discussed in detail in an earlier Energy Commission report *Understanding Entrainment at Coastal Power Plants: Informing a Program to Study Impacts and Their Reduction* (CEC 500-2007-120).

Findings and Future Recommendations

- The estimation and quantification of potential impingement and entrainment impacts continues to be important. Techniques for avoiding these impacts appears specie and application specific, and such impacts, when present, are unlikely to be eliminated fully by such techniques.
- The impact for other non-fish species that are potentially affected are not known, namely invertebrate species. A genetic approach allows for the identification of those species. These and other approaches that might be identified in the near future should continue to be applied in this context.
- Despite the addition of the species studied and described herein, there is a lack of specific life history data for the vast majority of California fishes. It is clear from both the biological data that are available and the modeling approaches that are employed, that the understanding of the potential entrainment impacts of once-through cooling exists for only a small handful of fish species, and this information needs to be expanded.
- A refinement of the modeling approach used to estimate potential impacts is warranted for multiple reasons:
    - The performance of models used to predict/estimate possible impacts is not completely understood.

- Targeted (known) species that are used to model impacts (because of limitations numbers 2 and 3 above) actually may not be good proxies for the entire community.
    - Uncertainty that surrounds the data input into such models affects the precision of the model output. Generally speaking, those parameters that relate to mortality of the early life stages are often the most important for producing reliable estimates of potential impacts from the models.
    - Determining effect size, which is a complex physical oceanographic process, requires specific biological and oceanographic knowledge of the region and the organisms living within it.
- More sampling effort may be required for determining possible entrainment impacts. Data herein suggest a three year interval as the most appropriate for the collection of such data.
- Sample size sufficiency will be important for precisely estimating possible impacts and for determining the mitigation that might be needed. While money might be saved by a reduction in sample effort, the models suggest that any savings will be countered by increased costs associated with a possible overestimate of the mitigation required for said impact.

Benefits to California

By protecting and conserving our natural resources, all Californians stand to benefit. The populations of fish and other species potentially affected by once-through cooling not only serve important roles in providing food and other direct benefits to humans, but also maintain opportunities for Californians in the areas of tourism and recreation, ecosystem health, and many other benefits that cannot be assigned a dollar value. It is essential to gain an understanding of the effects of once-through cooling on the marine environment to ensure ocean health for years to come.

Unless otherwise noted, all tables and figures are provided by the author.

1.0 Background

1.1. Once-Through Cooling Use in California

Twenty-one power plants in California use once-through cooling (OTC) technology, meaning that water is drawn into the plant, passed once by the condenser to remove waste heat and then discharged. Once-through cooling is different from wet cooling (where water is drawn in and recirculated past the condenser several times and cooled with cooling towers), or dry cooling (where air is used to transfer heat directly to the atmosphere). Once-through cooling technology passes water by the condenser one time before discharging it and uses the most water relative to all other types of cooling systems in California. Once-through cooling is used largely in older plants, circa 1950–1970, that are being retrofitted or repowered (using the old cooling water intake structure, CWIS) for use in meeting California's growing energy demands. These plants collectively have a generating capacity of nearly 24,000 megawatts (MW), and are permitted to draw nearly 17 billion gallons of water per day from coastal and estuarine waters (Foster 2005). Several of these plants have recently been retired or have announced intentions of retiring.

There are three predominant environmental impacts that occur using OTC: entrainment, impingement, and thermal effects. *Entrainment* is the capture of small, frequently larval, organisms in the water drawn in for cooling coastal power plants. These small aquatic organisms are carried along with the water into the plant where they are presumed (but see Mayhew 2000) killed by thermal, chemical, or physical effects (EA Engineering 2000; Environmental Protection Agency 2004). *Impingement* occurs when the cooling water intake traps larger organisms against the intake screens. *Thermal effects* are caused by cooling water when discharged at a temperature significantly above that of the receiving water body. All of these may affect individuals, populations, and communities.

Although entrainment, impingement, and thermal effects can all be environmental issues, this report focuses on entrainment for several reasons. More is understood about how to quantify and mitigate impingement and thermal effects. Impingement typically involves larger organisms that are easier to quantify because researchers can sample them directly on the screens, as opposed to indirectly estimating entrainment losses. Thermal effects are problematic primarily for those organisms that are sessile (i.e., not mobile). Again, these effects are sampled relatively easily because they can be directly assessed. Moreover, effects tend to be limited to relatively small geographic areas when compared with entrainment effects. Alternatively, the least amount of information is known about how to characterize entrainment impacts.

1.2. State and Federal Regulations

Thermal power plants larger than 50 megawatts (MW) are required to obtain a California Energy Commission license to construct and operate. Although many of the facilities using once-through cooling were constructed prior to the Energy Commission's existence, they are required to receive a permit for activities, including repowering or retrofitting, if those activities include increasing their generation capacity 50 MW or greater. As part of that process applicants may be required to conduct studies on entrainment and impingement and mitigate those effects. The use of once-through cooling water intake structures impact aquatic organisms by either impingement (organisms are pinned against screens at the entrance to the cooling water intake structure) or entrainment (organisms are small enough to pass through the screens and into cooling water systems where they are subjected to thermal, physical or chemical stresses).

In 2004 the United States Environmental Protection Agency (U.S. EPA) promulgated a new rule (Phase II) under the Clean Water Act Section 316(b) to reduce entrainment and impingement effects from cooling water intakes. As part of the process of quantifying those impacts and implementing measures to reduce them, operators were developing sampling plans and monitoring as part of the data collection. That information was needed prior to issuance of National Pollutant Discharge Elimination System (NPDES) permits. Under the rule, applicants were required to develop a Proposal for Information Collection (PIC). Clean Water Act Section 401 allows for states to implement the NPDES program, and in California, the Regional Water Quality Control Boards (RWQCBs) issue these permits. An NPDES permit is required for a power plant to use once-through cooling technology. Power plants are required renew their NPDES permit every five years. The U.S. EPA was sued on the new 316(b) rule by a group of litigants collectively known as Riverkeeper, Inc. and in January 2007 the court issued its decision (*Riverkeeper, Inc. v. EPA.* 2007) remanding sections of the rule back to the U.S. EPA to address including restoration as mitigation, best available technology, costs, and site-specific analysis. Recently, the U.S. EPA determined that the interim standard for compliance with 316(b) will be Best Professional Judgment until a new rule can be promulgated.

There are two other Clean Water Act 316(b) phases (I and III) for which the U.S. EPA recently developed rules. Phase I applies to new electric generating plants and manufacturers that withdraw more than two million gallons per day from U.S. waters if they use 25% or more of their intake water for cooling. Phase III addresses other existing facilities, as well as new offshore and coastal oil and gas extraction facilities that are designed to withdraw at least two million gallons per day.

In 2010, the State Water Resources Control Board (SWRCB) has adopted a *Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling* that establishes technology-based standards for implementing Clean Water Act section 316(b) within the state. The aim of these standards is to reduce the effects of cooling water intake structures on marine and estuarine life

The policy sets forth two alternative tracks for existing power plants to achieve this reduction. The first track would require a minimum 93 percent reduction in flow intake and essentially would require a power plant to be retrofitted to use cooling towers. For those power plants that can demonstrate to the RWQCBs that such an approach is infeasible, a second track is available that requires that entrainment and impingement levels are reduced using operational or structural controls to a level comparable to that resulting from the flow reduction set forth in the first track.

The California State Lands Commission and the Ocean Protection Council have also issued resolutions in regard to once-through cooling. Although the resolutions are nonbinding, they do identify OTC as an issue that needs to be addressed and recommend that the agencies seek to work collaboratively to reduce the impacts of once-through cooling.

1.3. Studies of Entrainment Impacts and their Reduction

As part of the scoping for the WISER program, in April 2005 Moss Landing Marine Labs hosted a Public Interest Energy Research (PIER)-funded workshop that brought together industry representatives, state and federal agencies, environmental groups, scientific and economic consultants, and academic scientists. The research eventually funded by WISER was based upon the needs identified at this workshop. WISER and the technical advisory committee (TAC) released a request for proposals (RFP) to solicit research to meet those needs in November 2006. The TAC, along with additional professional reviewers from outside the TAC, reviewed the proposals and selected seven Principal Investigators (PIs) for funding. Over the course of the following two years, these PIs executed their contracts and presented their findings at a Research Results Workshop held at the University of California Davis in January 2008, co-sponsored by the State Water Board. Each of those studies is summarized here, along with lessons learned from these studies when taken together. The authors note that an overview of existing methods for estimating entrainment impacts, not incorporating the results of these most recent studies, is summarized in the project white paper (Section 2 in Ferry-Graham et al., 2007).

The only other ongoing research program in the country that the authors know about is the EPRI program, which is funded largely through the efforts of utilities and the energy industry. EPRI has been publishing research results on once-through cooling since 1980 and have several targeted research programs in once-through technology and fish protection. The target is Clean Water Act 316 regulations, and includes thermal, impingement, and entrainment research. The program goal is to assess the effect of thermal power plant cooling system operation on fish and aquatic communities. Their research covers topics such as mitigation, analytical tools, and providing needed information and technical expertise to power plant operators that is useful for their compliance and regulatory needs. Highlights of the EPRI research can be found at www.epri.com and complete reports can be purchased through an annual subscription or on an individual report basis. EPRI does also provide newsletters, such as the *Technical News Quarterly,* which identifies recent research including those results that are published in peer-reviewed scientific journals. EPRI has funded several technology studies in conjunction with Alden Labs, including field studies, but these have not used California species or been applied under conditions analogous to coastal California. Much of the research is occurring in freshwater or in riverine systems on the East Coast or in the South. Most of the utilities that are members of EPRI are located outside the state, and EPRI conducts research in response to their members' needs. However, EPRI is conducting a few studies in California at present, including an assessment of the adverse impacts of cooling towers, and of fish protection technologies (Bailey 2007).

Table 1. PIER-funded WISER studies

Principal Investigators	Affiliation	Titles
Daniel Pondella	Occidental College, Vantuna Research Group	The Ichthyoplankton of King Harbor, Redondo Beach, California, 1974–2006
John Largier	University of California, Davis – Bodega	Improving Assessment of Entrainment Impacts Through Models of Coastal and Estuarine Withdrawal Zones
Joseph Cech , Timothy Mussen	University of California, Davis	Bright Vibrating Screens: Increasing the Detectability of Fish Screens
Jonathan Geller, Josh Mackie	Moss Landing Marine Laboratories	Evaluation of DNA barcoding and quantitative PCR for identification and enumeration of invertebrate larvae entrained by once-through seawater cooling systems
Liz Strange, David Cacella	Stratus Consulting	Improve impact assessment and mitigation
Pete Raimondi	University of California, Santa Cruz	Variation in impact estimation based upon measures of acceptable uncertainty
Charles Mitchell, Eric Miller	MBC Applied Environmental Sci.	Life History Parameters of Common Nearshore Marine Fishes

2.0 The Ichthyoplankton of King Harbor, Redondo Beach, California, 1974–2006

by Daniel Pondella, Jonathan P. Williams, and Eric F. Miller

Occidental College, Vantuna Research Group, 1600 Campus Road, Los Angeles, Ca, 90041

Typically, 316(b) entrainment characterization studies have been conducted over a single year and usually focused on the most abundant, economically important, and/or managed species. This leads to two critical unanswered questions which hamper the understanding of the ecological effects of our coastal generating stations: What is the overall community being impacted? and; how sensitive is this community to temporal variation? Since neither of these questions can be answered with a single year of data, Pondella and colleagues proposed to extend and analyze a unique long-term nearshore database to answer these questions.

The ichthyoplankton of King Harbor, Redondo Beach, California, has been monitored monthly utilizing the same methodology since 1974 (Stephens et al. 1986; Stephens and Pondella 2002). This monitoring program is unique because it is the only long-term nearshore ichthyoplankton data set in the Southern California Bight. It is also uniquely set proximate to three coastal generating stations withdrawing seawater from the southern one-half of the Santa Monica Bay: Redondo Generating Station (RBGS), El Segundo Generating Station and Scattergood Generating Station.

The density of larval fishes and plankton in King Harbor has decreased substantially during this 30-year sampling period (Stephens and Pondella 2002). Roemmich and McGowan (1995) described an 80% decrease in zooplankton volume in the California Current off Southern California since 1951 and the most precipitous decline occurring after the 1970s (McGowan et al. 1998). However, the CalCOFI data set is not collected in the nearshore environment (Moser et al 2001, Moser and Watson 2006), and as such its applicability for describing the nearshore ichthyoplankton community is limited. The extensive King Harbor database may provide greater resolution into the natural variability of this ecosystem, which is important for placing population level changes observed during shorter term 316b studies within a context of longer ecological time periods. This long term dataset will also be useful for determining the ideal length of 316b studies.

The long term King Harbor dataset analysis revealed that macroscale oceanographic processes (ENSO, PDO, Southern California Bight SST) were not significant factors in the change in larval densities over time. Instead, the major factor in the change over time was a long-term decline in larval catch, which appears to be the result of longer term changes in nearshore productivity. Individual larval taxa responded quite differently over the time series. Fishes with epibenthic larvae, such as croakers (*Genyonemuslineatus* and *Seriphus politus*) and gobies (Goby A/C complex and *Lythrypnus* sp.), were the only taxa influenced by power plant flow. These were also affected by maximum kelp density, determined by aerial imges, at Rancho Palos Verdes. When flow rates were greater, more larvae were caught. Similarly, more larvae were present when kelp density was high. No other larval types examined here were influenced by power plant flow rates. Nesting fishes (*Hypsypops and Hypsoblennius*), instead, were influenced by red tides and nearshore productivity. Similarly, declines in *Engraulis mordax* were linked to nearshore productivity changes.

Larval catch was statistically similar between the VRG King Harbor study and the Redondo Beach Generating Station's entrainment characterization survey. It is suggested that larval densities would be a good metric of fish stock status as this reduces the species-specific issues that individual biological taxa present. The pattern of variation among years in larval density is episodic, and a three-year interval would be necessary to accurately describe the long-term change in the community studied here. Longer time intervals would undersample the underlying patterns of change and cause the change to go undetected for many decades.

3.0 Improving Assessment of Entrainment Impacts Through Models of Coastal and Estuarine Withdrawal Zones

by John l. Largier, J. Wilson White, Linden Clarke and Kerry J. Nickols

University of California, Davis, Bodega Marine Laboratory, Bodega Bay, CA 94923

There are considerable challenges in quantifying the population-level effects of CWIS. First, natural rates of larval mortality are extremely high, so most entrained larvae would not have survived to enter the population. Second, the origins and eventual destinations of entrained larvae are difficult to ascertain, so the challenge is to determine how CWIS effects are distributed in space. At present there are several methods in use, but all rely upon several simplifying assumptions about circulation and population dynamics. It is unlikely that these methods yield appropriate results for coastal populations with complex patterns of larval movement and demography. Specifically, the existing methods do not recognize the dispersive nature of coastal flows nor the importance of a nearshore "coastal boundary layer", which dominates larval transport outcomes. Further, these models do not account for spatial structure in a population nor compensatory, density-dependent mortality after larval settlement.

The goals of this project were to use recent oceanographic observations over the inner shelf to develop heuristic models of nearshore circulation and population dynamics that reflect the key features of larval transport and post-settlement demography affecting population persistence. The authors used this modeling framework to demonstrate the importance of these features, to obtain better estimates of CWIS entrainment effects, to develop recommendations for CWIS placement, and to explore alternative metrics for quantifying CWIS effects. A major concern in describing planktonic larval transport is obtaining a proper description of inner-shelf, near-shore circulation. For exclusively coastal species, all larvae must begin their lives in the inner-shelf region, and all those larvae that leave the inner-shelf must return in order to settle successfully.

To characterize innershelf circulation, acoustic doppler current profilers (ADCPs) were deployed in a cross-shelf transect off of Huntington Beach, California in 2001. The authors also conducted preliminary analysis of similar deployments off Santa Barbara, Santa Cruz, Mission Beach and Moss Landing. These results, along with other data being collected in related projects at Bodega Marine Laboratory, support the existence of a coastal boundary layer – a region of slow-moving water over the inner shelf, with weaker mixing, resulting in slower alongshore transport than in faster-moving offshore waters. This type of boundary layer could temporarily retain planktonic larvae and shorten their typical dispersal distances.

The authors developed a Lagrangian particle-tracking model to simulate larval transport along a coastline containing a CWIS. This model included a mathematical representation of a coastal boundary layer similar to that detected in the Huntington Beach data. This particle-tracking model described the movement of individual particles released from a particular nearshore position as a result of advection (transport by mean flow) and diffusion (transport by zero-mean flow variability). The authors ran the particle-tracking model with flow parameters geared towards two different time scales: The first was the time scale of a typical pelagic larval duration (PLD) (days-weeks, representing a single dispersal event), and the second was the time scale of population dynamics (months-years, representing circulation averaged over multiple spawning seasons within the generation time of a population). In general, dispersal patterns were not affected by the exact shape of the tri-linear function used to describe the mean flow (advection) (Largier et al, in review). This was encouraging because it suggested that our imperfect knowledge of the nature of cross-shelf boundary layer profiles does not strongly affect model results, so long as this quiescent nearshore zone is recognized. Conversely, the values chosen for the diffusive component of circulation did strongly affect larval transport (Largier et al, in review). Higher along-shore diffusivities produced broader spatial distributions of larval settlers and rapidly removed larvae released near a CWIS site, so that most entrainment happened immediately after spawning. Higher cross-shore diffusivities carried more larvae offshore, which also increased alongshore dispersion, but few returned to settle. This reduced the total number of larval settlers and also reduced the overall entrainment of larvae after the first several days post-spawning. This result reinforces the need to be precise about the scale under consideration – using high-advection short-timescale patterns to predict population-time-scale results (which aggregate over longer term variations) would lead to errors.

There is a strong suggestion from these model runs that larvae are more commonly entrained very soon after spawning rather than later in their life (Largier et al, in review). The rate of entrainment of latestage larvae never exceeds that of early-stage, a pattern that would be amplified by a constant rate of larval mortality (not included in these models) that would result in many fewer larvae available for entrainment later in the larval period. However, each late-stage larva has a much higher chance of survival and thus much greater value – suggesting that attention should be focused on these latestage larvae.

In order to examine the effects of entrainment on population dynamics, the authors ran the particle-tracking model with long-time-scale parameter set to estimate dispersal kernels for a population occupying a 100 km coastline with a CWIS in the center. The authors then simulated population dynamics for two types of populations: one that was unexploited and healthy, with relatively long average postsettlement lifespan, and one that was overexploited and on the verge of collapse, with an average post-settlement lifespan that was relatively short. (The connection between population collapse and lifespan is that longer-lived individuals spawn more eggs over their lifetime, giving them more opportunities to successfully replace themselves with an offspring. The population persists only if each adult replaces itself with at least one offspring on average).

In no case did CWIS affect the dynamics of a healthy population, regardless of intake rate (even intake rates 10x the maximum observed in California CWIS) or distance offshore (Largier et al, in review). This was not true for populations near collapse, however. For these populations, the addition of CWIS often led to population collapse for intake rates similar to the maximum observed in CA. This was always the case for CWIS in the nearshore (just 50 m offshore; i.e., very close to where larvae were spawned), but CWIS further offshore led to collapse in some simulations but not others. When two CWIS were placed 10 km apart, their cumulative effects exceed that of a single CWIS and only rarely did near-collapse populations persist in simulations. Even when CWIS entrainment did not cause near-collapse populations to go extinct, it did drastically increase the time it took for a population to recover from a catastrophic localized disturbance to pre-disturbance population densities.

The results of the metapopulation model led the authors to examine more closely the traditional measures used to gauge CWIS impacts on populations: Adult Equivalent Loss (AEL), Fecundity Hindcasting (FH), and the Empirical Transport Model (ETM). All three are flawed to varying degrees (Largier et al, in review). The authors used the circulation model to simulate reality and then applied the calculation of AEL and FH in the model population and also calculated the "actual" value the statistics are intended to estimate. In all cases the authors examined, the two sets of values were off by large margins, often orders of magnitude. Moreover, the sampled values of those two statistics and ETM-derived P_M had no apparent relationship to the actual effect of entrainment on the population. These errors appear to derive from several systemic problems with the traditional statistics, including the lack of appreciation for the role of compensatory density-dependent mortality, variability in the eventual destination of entrained larvae, and the fact that healthy populations will spawn more larvae – and thus have more larvae entrained – than populations near collapse.

Some of the future directions for improving assessment of the impact of cooling water intake systems on larval mortality (and thus coastal marine populations) would target specific sites. Actions could include:

- Flow observations: Make use of data obtained from Coastal Ocean Observing Systems.
- Transport models: Make use of transport models to assess larval loss through entrainment.
- Larval observations: Analyze records of larvae entrained and of larvae in plankton surveys.
- Population models: Use of population models to assess impact of enhanced larval mortality on population levels.
- Assessment protocols: Development of new protocols for compliance.
- Ecosystem-based management: Development of protocols that assess impact of cooling water intake in concert with other stressors and management actions in coastal waters.
- Operational management: Consideration of changes in management of intake systems.

4.0 Variation in Impact Estimation Based Upon Measures of Acceptable Uncertainty

by Peter Raimondi

Department of Ecology and Evolutionary Biology, Long Marine Laboratory

University of California Santa Cruz, 100 Shaffer Road, Santa Cruz CA 95060

The recent history of entrainment impact assessment in California using 316B guidelines has relied heavily on the use of Empirical Transport Models (ETM). Often ETM isused in conjunction with other models that translate larval losses to adults using either hindcast (Fecundity Hindcast, FH) or forecast modeling (Adult Equivalent Loss, AEL). However the utility of the FH and AEL models has been hampered by the need for species-specific life history information that is lacking for many species entrained in California. ET models, instead, estimate the percentage of larvae at risk that were killed due to entrainment (called PM or proportional mortality) and the area of the population at risk (called source water body: SWB = 1/PS using ETM notation). The species-specific product of PM and SWB gives the Area of Production Foregone (APF), which is an estimate of the area of habitat that, if provided, would produce the larvae lost due to entrainment.

Importantly, APF estimates should be much more robust to life history variation than either FH or AEL estimates. Hence, some measure of APF should then be a proxy for all other species entrained but not directly modeled. Typically, mean APF has been used in this context, but recently the 80% confidence limit was used in a case before the California Coastal Commission (Poseidon Resources [Channelside] 2008). There have been no standards developed for using a mean or a larger measure of statistical uncertainly such as the 80% confidence limit, largely because the authors have yet to assess of the effect on the models of larger measures of uncertainty, and also because the method of incorporation of uncertainty (or error) has not been vetted. Similarly, recent determinations using ET models have calculated the average proportional mortality across target species and used this as the best estimate of proportional mortality for all entrained organisms. The major, thus far untested, assumption is that target species are good proxies for other species not targeted or otherwise measured. The goals of this project were to evaluate the effect of (1) incorporation of statistical error in estimation of APF and (2) variation in sample size (number of species for which APF is assessed) on estimation of APF. For Goal 1, both resampling theory and traditional parametric approaches were utilized, while resampling theory was the basis of the approach to address Goal 2.

In every simulated combination of power plant, sample year, larval duration and habitat confidence levels (uncertainty) calculated using parametric and resampling methods yielded similar results. The overall relationship revealed an exponential pattern whereby increases in confidence levels, hence increases in the likelihood of complete compensation of effects, resulted in increasingly larger percent increases in APF (the area of habitat required to produce the larvae lost due to entrainment). Increasing the likelihood from 50%, which represents the mean, to 95%, which is the traditional value used in inferential statistics, increased the required area by about 50% (across all studies). Using a more conservative increase from 50% to 80% yielded an increase in area of about 25%. Assuming a direct relationship between area and cost, this means that by increasing the likelihood of attaining full compensation from 50 to 80% one would add an additional 25% to the cost of the mitigation project.

Because standard errors were calculated for each PM value, it was possible to calculate confidence values for each targeted species (Raimondi, in review). When species-specific PM confidence values were incorporated into the models, the resultant APF estimates were typically much larger. The statistical-philosophical basis of this method of incorporation of measurement error is that the calculation of PM and APF values for each species accurately describes (after error is accounted for) the impact to the species. This suggests that modeled (=target) species are likely not good proxies for those species not targeted or otherwise measured. Under this logic, the goal would be to ensure that the area restored or created was sufficient to compensate for the losses to each species at a given confidence level. While appealing, there are problems with this approach. First measurement errors associated with PM are often massive, and likely inappropriate for the task of generation of confidence values. Second, there is no provision for estimation of the impact for species not assessed (which are the vast majority of species). Third and most fundamental, estimation of confidence values based on species specific error rates is counter to the logic of the calculation of mean APF. That is, the replication for the estimation of mean APF is the species-specific APF values (not error rates), therefore the error must be based on the same replication (see Quinn and Keough 2003). Thus, using species-specific confidence values is not practical or recommended.

Finally, the number of species sampled dramatically affects estimation of APF (Raimondi, in review). As expected from sampling theory (Quinn and Keough 2003, Zar 1996), resampling data revealed that, for all confidence levels *above* 50%, the APF (estimated area required to compensate for an impact) decreased as a function of the number of species assessed. There was no effect of sample size on APF with confidence levels at 50% or below, though at smaller sample sizes there was greater variability around the estimate of APF.

If policy mandates that the 50% confidence limit for the APF value (~mean) be used to assess impacts and as a measure of compensatory mitigation, sample size is theoretically unimportant, because the expected mean does not vary with number of species assessed. Note that this does not mean that the actual mean APF will be the same across sample size. Indeed at smaller sample sizes there will be much more variability in the mean if sampled repeatedly. This would lead to a greater probability of under or over estimating the impact than would occur at higher sample size. By contrast to the situation where policy mandates use of the 50% confidence limit for APF, if policy or regulation requires incorporation of confidence values higher than 50% (e.g. Poseidon case where 80% level was used), then sample size becomes even more important. This is because the likely mitigation requirement will decrease with increasing sample size. The key implication of this result is that minimizing cost during sampling and assessment may be countered by the increased cost of habitat creation or restoration due to inadequate sampling.

5.0 Life History Parameters of Common Nearshore Marine Fishes

by Eric Miller and Charles Mitchell

MBC Applied Environmental Sciences, 3000 Red Hill Avenue, Costa Mesa, CA 92626

The assessment of the effect of once-through cooling on fish populations can be very problematic, especially that of the larval life stages. Frequently, estimated larval entrainment may number in the millions, and sometimes billions. These numbers are generally incomprehensible and not descriptive of the ultimate impact on adult populations. Life history parameters, those aspects that determine population growth, determine the potential impacts to adult populations. A million or more larvae of a single species can represent the loss of a few adults to the standing stock, especially for those highly fecund species such as northern anchovy.

Much of the life history information needed for fish species is archived in their otolith, or ear bone. This bony structure has long been established to act as the natural chronometer for the fish, similar to that of rings on a tree. Knowing parameters such as longevity and age class abundance can lead to calculation of mortality rates for that species. When coupled with other, and often easier obtained, data like length, weight, and sex, how fast a species grows, when it generally reaches sexual maturity, and the age structure of the population or fishery landings can be determined. Analysis of the reproductive organs can reveal what time of year the species will spawn, the length of the spawning season, female spawning frequency in one season, the number of eggs a female can produce at one time (batch fecundity), the variation in egg production with age and size, the potential or occurrence of sex change in the species during its lifetime, and the presence of any social structure to the spawning.

Such parameters feed into the demographic models biologists use to assess impingement and entrainment impacts. Some of the aforementioned parameters may not be used directly, but are required to determine other parameters such as mortality. Different varieties of these models utilize some, or all, of these parameters to convert raw abundance estimates to a more readily usable metric, such as Age-1 equivalents. For instance, if the age, length, weight, sex, sex ratio, batch fecundity, length of spawning season, number of spawns by typical female in one season, and longevity were documented for a representative sampling of a specific species, the necessary parameters for nearly all of the demographic models can be calculated. From the data just gathered, the age-at-length, mortality (survival), annual fecundity, total lifetime fecundity, age at first maturity, and total lifespan could be either directly observed or calculated. These represent the majority of all the parameters required for executing models such as Adult Equivalent Loss (AEL) or Fecundity Hindcasting (FH), which are commonly used in power plant assessments. Unfortunately, these parameters have been described for only a handful of California's marine species. Most of these descriptions involve species with commercial value, such as northern anchovy. The life history of most common nearshore fish is a mystery since few support a commercial, or even recreational, fishery.

This study was designed to fill in some of these knowledge gaps. Specifically, the study aimed to characterize some life history parameters of queenfish (see also Miller et al., 2009), white croaker, spotfin croaker (see also Miller et al., in press), and yellowfin croaker (see also Miller et al., in press; Pondella et al., 2008). All four species were commonly taken in impingement and/or entrainment studies in California, with queenfish and white croaker consistently ranking among the most abundant recorded in both survey types. These parameters, in addition to what has been previously published, can take fishery analysis several steps closer to opening up these species to the more rigorous demographic modeling techniques.

Adult age and growth, or the annual growth rate of adults by species, was described using otolith analysis. Queenfish and yellowfin croaker from Southern California were collected and their otoliths analyzed to determine the annual growth rate for each species. The growth rates were described by the von Bertalanffy model. Von Bertalanffy parameters for queenfish were $L_\infty = 181.12$, $k = 0.27$, $t_0 = -1.408$, and $n = 820$. Those for yellowfin croaker were $L_\infty = 307.754$, $k = 0.278$, $t_0 = -0.995$, and $n = 1209$. Sex-specific growth rates in each species differed significantly, with females growing faster.

The spawning season was empirically determined for yellowfin croaker based on histological examination of the gonads. The size and state of oocytes (developing eggs) in females as well as the condition of the testis in males were evaluated based on time of collection for 86 individuals. This analysis indicated yellowfin croaker spawning began by June, peaked in July, and was complete by September. The condition of oocytes principally demonstrated this, but the relatively uncommon finding of a regressing male (a male no longer actively producing milt for the season) collected in September also confirmed the spawning season had ended. Lastly, the calculation of the proportion of the body weight comprised by the gonads, or the gonosomatic index, further supported the identified spawning season.

Batch fecundity, or the estimation of how many eggs a female of a given size can produce, was documented for spotfin croaker (n = 13) and yellowfin croaker (n = 16). Egg production in both species increased at an exponential rate with the increase in size, length, and weight. Individuals that were likely reproductively active were used in the batch fecundity analyses. Only spotfin croaker females with a gonosomatic index greater than 3.0% and yellowfin croaker females with a gonosomatic index greater than 3.5% were analyzed. The relationship between standard length (SL) and batch fecundity (BF) in spotfin croaker was described by the equation $BF = 2E\text{-}07SL^{5.0109}$ ($R^2 = 0.79$). Weight (g) to batch fecundity in spotfin croaker was described by the equation $BF = 13.511Wt^{1.6032}$ ($R^2 = 0.85$). In yellowfin croaker the equations $BF = 31658e^{0.0066SL}$ ($R^2 = 0.51$) and $BF = 95973e^{0.0015Wt}$ ($R^2 = 0.57$) best described batch fecundity.

Larval daily growth rates were determined for queenfish (n = 122), spotfin croaker (n = 100), and white croaker (n = 68). All three species exhibited gradually declining growth with age and significantly greater growth rates during the warmer summer months than during the winter and spring months (Miller et al, in review). This was most likely an effect of the seasonally warmer water temperatures.

These studies have only begun to expand the available pool of life history parameters for common Southern California marine fish. It is recommended that similar studies continue on these and currently unstudied species to determine basic population parameters, and how those are changing over time in order to place potential power plant impacts within a context of larger population-level fluctuations.

6.0 Methods for Improved Impact Assessment and Mitigation

6.1. Restoration to Offset Environmental Impacts of Coastal Power Plants

by Elizabeth Strange, Dave Cacela, Michael Carney, Susan Humphries, and Joshua Lipton
Stratus Consulting Inc., Boulder, CO 80306 and Washington, DC 20036

While restoration as a tool remains ambiguous after the recent rulings with regard to Riverkeeper II, restoration is still a useful and viable tool for permitting agencies. For example, in some cases, even the best technology available (BTA) cannot eliminate all environmental impacts that may result from power plant operation. Permitting agencies may seek methods of restoration to offset losses that continue to occur. Because of the continued importance of restoration in this and other contexts, California will need reliable methods to quantify the production of organisms in restored habitats, both to estimate the amount of restoration needed to offset losses and to determine restoration success. In this context, restoration scaling is a quantitative technique, typically based on ecological methods, for estimating the restoration gain needed to offset a given magnitude of loss (Strange, in review a). In this case, it applies to entrainment losses at coastal power plants that use once-through cooling.

The main goals of this project were to provide an overview of restoration scaling, to evaluate the HPF method as it has been used to scale restoration in California power plant studies, and to recommend ways to improve the data and methods used for restoration scaling to offset entrainment losses.

An evaluation of the habitat production foregone (HPF) method that has been used to scale restoration in some power plant cases indicates that it often is not a valid measure of the increase in fish production expected from restoration (the restoration gain). The HPF often is not a reliable measure or estimate of recruitment or productivity. It is an estimate of the amount of habitat within a waterbody that could contain the quantity of larvae entrained based on the fraction of the larval population lost to entrainment mortality. For example, the HPF assumes that if 10% of the larval population is entrained, then these larvae must occupy the same fraction of the source water area (SWA) (i.e., 10% of the SWA).

Comparison of HPF results with restoration estimates using appropriate scaling techniques indicates that the HPF method may significantly underestimate the amount of habitat restoration needed to offset a given magnitude of entrainment loss. This could be a serious problem whether or not restoration is actually implemented because the costs associated with HPF restoration estimates are sometimes used in permitting and settlement negotiations about required technologies to minimize impingement and entrainment.

When properly applied, restoration scaling can be an objective, quantitative, and transparent approach for determining the amount of restoration needed to offset impingement and entrainment losses. There is a substantial and growing literature on appropriate methods for conducting restoration scaling. It is suggested that the appropriate restoration scaling metrics for fish include measures of recruitment, the addition of new recruits to the population per unit area per unit time, or productivity, the rate of biomass production per unit area per unit time.

6.2. Life History Sensitivity Analysis

by Elizabeth Strange

Stratus Consulting Inc., Boulder, CO 80306 and Washington, DC 20036

Demographic models are among the methods used to assess the importance of impingement and entrainment-related losses of aquatic organisms that result from the operation of cooling water intake structures at power plants that use once-through cooling for electric energy generation. The models convert numbers of organisms killed at various ages, usually fish eggs and larvae, into standardized metrics. The Adult Equivalent Loss (AEL) model converts losses of early life stages into equivalent numbers of adults of a given age. The Fecundity Hindcasting (FH) model estimates the total number of adult females required to produce the number of larvae lost to entrainment (i.e., equivalent spawners). The Forgone Yield (FY) model is used to estimate the yield (biomass) of fishery species not harvested because fish are killed by impingement and entrainment.

Demographic models require data on species- and age-specific fecundity and mortality rates. However, for most fish and aquatic invertebrates values for fecundity and mortality parameters have a high degree of uncertainty. The uncertainty in input data translates into uncertainty in model predictions, complicating the interpretation of model results. As a result, conclusions about the ecological significance of impingement and entrainment can vary depending on the input data used to generate model results. Although understanding the uncertainty in demographic models is therefore critical for evaluating impingement and entrainment losses, few quantitative analyses of uncertainty in this context have been conducted.

The overall goal of this study was to quantify how uncertainty about the values of the input parameters of the AEL, FH, and FY models translates into uncertainty in calculated measures of impingement and entrainment losses, and to determine the relative contribution of individual parameters to total uncertainty. Results of these analyses will provide regulators a better understanding of the uncertainties associated with reported impingement and entrainment loss rates. The results will also help to guide and prioritize future data collection efforts designed to improve the reliability of impact assessments of 316(b) facilities.

An extensive literature review assembled demographic parameters for seven species groups commonly impinged and entrained in California: anchovies (*Engraulidae*), gobies (Gobiidae), blennies (Blenniidae and Chaenopsidae), California halibut (*Paralichthys californicus*), rockfishes

(*Sebastes* spp.), surfperches (Embiotocidae), and crabs of the genus *Cancer*. Based on this review, the authors identified a "best estimate" and reasonable ranges of values for each input parameter evaluated. This information was used to construct a distribution of values for each parameter.

Using Monte Carlo simulation, a method for statistical sampling from distributions of parameter values, the researcher team conducted a sensitivity analysis to estimate the uncertainty associated with different applications of each model. In each of thousands of simulations of a given model, values for certain input parameters were randomly sampled from the distribution of values and were used to calculate the value of the demographic metric. By conducting multiple simulations with systematic differences in which parameter values were variable or fixed as constants, the relative contribution of each parameter to total uncertainty was quantified and ranked, a procedure known as a "factor prioritization." The results of the simulations were also quantified as a coefficient of variation (CV) that was used to describe the relative precision of results provided by the various demographic models. For this analysis, the CV is the standard deviation among outcomes for a particular simulation divided by the point estimate for a particular application.

The FH model tended to be the most precise of the three models for most species evaluated. Uncertainty in larval mortality rates was the largest source of uncertainty for most species using the AEL model, except for rockfishes, where mortality of young-of-the-year (age 0+) fish was the greatest contributor to uncertainty. Similarly, uncertainty in mortality rates of early life stages was the largest contributor to model uncertainty for most species when applying the FH model. However, uncertainty about lifetime fecundity was the largest contributor to uncertainty for anchovies and blennies when using the FH model.

Because of the different ages of impinged and entrained species, a model that provides the most precise estimate for evaluating impingement may not provide the most precise estimate for evaluating entrainment. For assessing entrainment, the FH model was more precise than either the AEL model or the FY model for most species. For assessing impingement, the precision of the AEL model was greater than the other models for all species the authors evaluated.

For a given facility, uncertainty in results of the AEL applied to entrainment could be made more precise by collecting locally specific larval morality rates, assuming that such studies provide mortality estimates that have less uncertainty than the estimates from the literature review. This is consistent with the fact that larvae dominate entrainment losses. However, the available literature indicates substantial uncertainty regarding larval survival for most species, suggesting that it could prove difficult to improve larval survival estimates, even with local studies. Uncertainty in results of the FY applied to entrainment could be made more precise by acquiring more precise estimates of mortality rates among older age classes, particularly age classes vulnerable to fishing mortality.

Alternatively, the authors' results suggest that the FH model may be the most reliable way to assess entrainment losses, particularly if more precise estimates of lifetime fecundity are identified. It is likely that improving estimates of lifetime fecundity will not only be more tractable, but also less costly than obtaining more precise estimates of larval mortality rates.

6.3. Cumulative Impacts

by Elizabeth Strange

Stratus Consulting Inc., Boulder, CO 80306 and Washington, DC 20036

Cumulative environmental impacts can be evaluated at different levels of biological organization (individual, population, community, and ecosystem), depending on available data and assessment goals. This report discusses models at all of these levels and their potential use for impingement and entrainment studies at California's coastal power plants.

The Empirical Transport Model (ETM) is commonly used in California for single-facility assessments of entrainment of larval populations, and therefore ETM results provide readilyavailable data for cumulative impact analysis. However, the high natural mortality rates of early life stages mean that models of larval populations are limited to evaluation of the current generation. Models of adult populations, such as Leslie matrix-based models, can evaluate cumulative impacts on a population over multiple generations, but have limited value for cooling water intake studies because of the dozens of species that are typically affected in a given water body. Food web models address this shortcoming, and the publicly available EcoPath/EcoSim software makes development of such a model relatively straightforward. However, food web models are very data-intensive and require data that are often unavailable for coastal fishes, particularly forage fish, which make up over 90% of impingement and entrainment losses.

This review considered the potential use of available approaches for studies of the cumulative impacts of cooling water intakes, with a focus on the Empirical Transport Model (ETM). The ETM is commonly used in California for single-facility assessments of larval entrainment, and therefore results provide readilyavailable data for cumulative impact analysis. Despite this advantage, however, the report concludes that the high natural mortality rates of early life stages restrict the use of larval population models to evaluations of impacts to the current generation only. This disadvantage can be overcome by using one of the available models of the adult populations of impinged and entrained species, such as Leslie matrix-based models, which can evaluate cumulative impacts on a population over multiple generations. However, population models cannot analyze impacts on the entire community of species that are affected in a given water body. Food web models address this shortcoming, and the publicly available EcoPath/EcoSim software makes development of such a model relatively straightforward. However, food web models are very data intensive, and require data that are often unavailable for coastal fishes, particularly forage fish that make up over 90% of impingement and entrainment losses.

Because all of these modeling approaches involve various tradeoffs among data availability and ecological significance, the review recommends an iterative approach to cumulative impact assessment. An iterative approach would begin with a screening level analysis of individual losses and proceed to the assessment of higher level endpoints depending on thresholds of concern and assessment goals.

7.0 Evaluation of DNA Barcoding and Quantitative PCR for Identification and Enumeration of Invertebrate Larvae Entrained by Once-Through Seawater Cooling Systems

by Jonathan Geller and Josh Mackie

Moss Landing Marine Laboratories, Moss Landing, CA 95039-9647

One difficulty in assessing community-level impacts of once-through cooling (OTC) systems is the difficulty of identification and enumeration of the larvae of benthic organisms that may become entrained and killed. In this study the authors investigate DNA barcoding, a way of identifying species based upon their unique genetic signatures, and quantitative polymerase chain reaction (QPCR), a way of rapidly detecting and quantifying the amount of target DNA in a water sample, as potential tools for determining species identifications from cooling water.

For DNA barcoding, 1101 planktonic organisms from 12 plankton samples (taken November 2006-May 2007) were extracted (Geller and Mackie, in review). These were photographed, used for DNA extraction, and the majority entered into a Web-accessible database. 168 COI (Cytochrome c oxidase subunit 1). Ninety-eight unique DNA sequences, or "barcodes" were obtained that were consistent with "known" taxa. The additional DNA sequences corresponded to "unknown" taxa and were largely bacterial in origin, and thus were further discounted from consideration here. The majority of "known" organisms sampled and sequenced were annelid, molluscan, or crustacean. The average match of these non-bacterial sequences to GenBank records, the most well developed genetic database, was only 16%. This indicated that species were matched typically at the genus or family level of identification, given a reliable indication of identification at this level only. This result is due largely to the fact that the Californian estuarine biota is poorly represented in existing genetic databases.

For evaluating QPCR, artifical systems were created by seeding bulk (unsorted) seawater with known amounts of *Artermia*, and these were then sampled to determine the ability to subsequently detect those amounts (Geller and Mackie, in review). The COI and 18S rRNA gene probes with Taqman and SYBR Green reporting systems were exquisitely sensitive in detecting *Artemia* nauplii in DNA extractions from bulk, unsorted plankton: a single nauplius is easily detected when added to 20 mg of wet, packed plankton and distinguished from two added nauplii.. Indeed, *Artemia* DNA diluted to 10^{-4} ng reaction^{-1} (equivalent to 10^{-5} nauplii) was detectable. Background plankton DNA had no effect on specificity of reactions, alleviating concern for errors caused by similar organisms in the background plankton community. Some natural plankton DNA and purified herring sperm DNA were inhibiting of PCR above 100 ng reaction-^{1}, but these samples could be diluted to eliminate inhibition. Because QPCR could detect 10^{-5} of one nauplius, dilution solves inhibition without sacrificing sensitivity. Overall, QPCR was specific, sensitive, repeatable, and robust for determining plankton densities.

Therefore, two key recommendations are: 1) the continued development of molecular methods for plankton characterization from unsorted plankton, and 2) most importantly, focused effort to barcode identified adult samples for the purpose of building a genetic database adequate for then identifying larvae from DNA sequences. The authors conclude that QPCR can be applied to real-world analysis of focal organisms, particularly once the above databases are established, and that *Artemia* nauplii (being absent from most aquatic environments) can be routinely added to plankton samples to serve as an internal control for all steps in the procedure.

8.0 Bright Vibrating Screens: Increasing the Detectability of Fish Screens

by Joseph Cech and Timothy Mussen

Center for Aquatic Biology and Aquaculture, University of California, Davis, 95616

The withdrawal of large amounts of water at cooling water intake structures (CWIS) can be lethal to residential and migratory species that become entrained in the influent current. Some intake structures feature screens and louver (primarily fresh water) arrays in front of their water inlet to prevent juvenile and adult fish from being displaced from their habitat. However, the screens or louvers, themselves, can be fatal to fish if the fish contact or impinge on them severely or repeatedly. The effectiveness of fish screens and louvers for protecting marine fishes, in particular, is mostly unknown. Adding industrial vibrators or strobe lights to screens may improve the effectiveness of screen detection by nearby fishes.

The author'sOur objectives were to determine the sensory stimuli that different fishes use to recognize the presence and threat of fish screens/louvers and to suggest new screen/louver modifications that may improve fish passage. To meet the authors'our objectives, laboratory experiments testing swimming performance and behavior were conducted on freshwater and marine fishes. Freshwater steelhead (*Oncorhynchus mykiss*) and Sacramento splittail (*Pogonichthys macrolepidotus*) were tested in an indoor flume on the UC Davis campus, and marine shiner surfperch (*Cymatogaster aggregata*) and staghorn sculpin (*Leptocottus armatus*) were tested in an indoor flume at the UC Davis Bodega Marine Laboratory. The experiments consisted of 15-minute trials where fish were observed swimming in front of either wedge-wire fish screens or louver arrays. Experimental variables consisted of light level (day vs. night), vibrations from industrial vibrators, and strobe light flashes.

Streptomycin treatments were used to temporarily 'disable' the fishes' primary sensory system for detecting the screens, the lateral line. Fish are likely to rely on visual cues to direct their swimming during the day, but vibrations detected by the lateral-line system may also play an important role in fish screen detection and avoidance, especially during the night. The lateral-line system in fish is comprised of superficial and canal neuromasts that are sensitive to water movements and near-field sound vibrations. Using the lateral-line system fish can determine the speed, direction, and turbulence of the water surrounding their bodies and detect the location of stationary and moving objects near their bodies in a current. The entire lateral-line system can be blocked by the application of streptomycin, which cleaves the hair cells from the fish making their neuromasts non-functional, to the fish's water supply. To determine if the streptomycin treatments were effective at blocking the fishes' lateral-line system, lateral line cells of treated and control fish were stained with DASPEI, a mitochondrial stain, and viewed under a fluorescent microscope. Streptomycin-treated fish are compared with control fish to determine the importance of the lateral-line system in specific behaviors.

The general outcome was that all the fish contacted the screens more frequently at night and were more likely to become permanently impinged on the screen at night. In the nighttime trials, a higher percentage of fish passed through the louver arrays than became permanently impinged on the screens. However, fish contacted the screen and louvers in every set of experiments indicating that if a barrier was not in place, most fish would have been drawn through the simulated diversion. The reason that most fish contacted and impinged on the screen and louvers less frequently during the day is probably because they were using visual cues, which are not available at night, to perceive the screen and avoid it. During night fish were commonly observed drifting back toward the screen and then swimming just before they came in contact with it. These observations indicate that either the fish were able to detect the screen at night, through their lateral-line system or sensitive low-light vision, or they had learned the screen's location by remembering where they contacted it earlier in the trial.

The shiner surfperch and staghorn sculpin, both marine fishes, showed a significant decrease in contacts with the screen when it received low-frequency impacts from the vibrator (like a large hammer hitting the screen every 1.5 seconds). The fish would commonly burst-swim forward into the current and away from the screen every time the vibrator struck at the start of the trials. These results indicate that low-frequency, near-field vibrations can help repel some marine fish from contacting screens. Interestingly, the vibrating screens were mostly ignored by fish in the freshwater treatments, probably because the vibrators used in these trials all ran at frequencies that were out of the target range of 10-15Hz that may repel fish. Also, the marine louvers frequently allowed the fish to pass through them on their first approach.

In the strobe-light treatments, staghorn sculpin actively swam away from the lighted screens and louvers shortly after coming to rest on them and sometimes before they made contact showing that strobe lights may make an effective deterrent for this species. However, surfperch and steelhead actually contacted the screens more frequently during nighttime trials while flashed by the strobe light. Thus, more research is required before making conclusions about the most effective combination for repelling coastal fish community from water intakes.

The experiments indicate that fish screens and louver arrays placed in front water diversions may allow fish to potentially escape entrainment. Fish avoided contact with screens and louvers to a greater extent during the day than night, which suggests that pumping should be reduced during the nighttime. The findings show that different fish species rely on both visual and mechanosensory cues, to different degrees, to detect and avoid physical barriers while swimming in a current. The increased screen contact rates seen in the splittail and surfperch treated with streptomycin during the nighttime indicated that their lateral-line system sensory inputs assisted these fish in avoiding the screen. The other two species apparently use their lateral-line systems to lesser extents, while avoiding screens. Vibrating devices that emit low-frequency, strong near-field vibrations may have potential at repelling fish, but further testing is needed (preferably with a device that vibrates in the 10-15Hz range) before any general statements can be made. Strobe lights may also be an effective deterrent, but the fish must have a space to swim to, away from the flashes, to make them effective. Behavioral guidance devices directed at either sensory system can be effective at guiding fish away from hazards, but they may only be effective under certain conditions (e.g., nighttime) or for certain species. Installing screens to prevent fish passage may be desirable over louvers, but louvers are preferable for fish protection over an open (i.e., unscreened/louvered) diversion.

9.0 Emergent Lessons

The goal of this research funded here, collectively, was to provide better tools for determining if there are impacts, determining basic information about potentially impacted species, and exploring new ways of reducing those potential impacts. While enhancements to screening technology may work to deter some species, the effectiveness may vary among species and among screening applications, as revealed by the study by Cech and Mussen. There are also new data that suggest low survivability of commonly impinged fishes once they become impinged, even if they are returned using fish return systems (Miller, 2007). In addition, avoidance technology and return systems will not be effective for small organisms, such as invertebrates, that readily pass through the screens. Thus, the estimation and quantification of potential impingement and entrainment impacts continues to be of importance.

It is clear from both the biological data that are available, and the modeling approaches that are employed, that the potential entrainment impacts of OTC for only a small handful of fish species are understood. The work on commonly entrained species by Miller and Mitchell adds a significant amount to this understanding because such specific life history data for the vast majority of California fishes is lacking. This finding is further exemplified by the work of Strange and colleagues.

It is also clear that there are other species that are potentially affected, namely invertebrate species. The genetic approach allowed for the identification of those species. A common argument against genetic approaches is that such data are expensive to obtain, due to the large amount of technology (i.e, specific machinery) required to extract the information. However, visual analysis of larvae, as is typically used at present, is also extremely expensive because it requires a tremendous investment of time and personnel just as well-trained as the personnel required to process genetic samples. In addition, larvae smaller than fish larvae typically are not, or cannot be, identified because they are either unknown, relative to the identification keys available, or simply too small. Growing the larvae up to larger sizes, which would solve either problem, is unfeasible under most laboratory conditions. Larvae typically do not survive, even if sufficient space were available to undertake such an effort.

This lack of information may well be hindering the ability to effectively predict possible impacts, as many models require this level of specificity, as noted by Raimondi in his review. Models that do not require this level of specificity still have within them inherent assumptions regarding the biology of the larval community being potentially affected. Raimondi's models revealed that targeted (known) species may not be good proxies for the entire community. Research by Strange et al. summarized here further suggests that the uncertainty that surrounds the data that is input into such models can, obviously, affect the precision of the model outcome. However, not all species predictions are affected the same way, and the parameters that need to be estimated most precisely can vary among species. Generally speaking, those parameters that relate to mortality of the early life stages are often the most important for producing reliable estimates of potential impacts from the models. This is further exacerbated by the limited ability to predict the effect size, or the area over which the potential effect should be estimated. As demonstrated by Largier, determining effect size requires specific biological and oceanographic knowledge of the region and the organisms living within it. Determining effect size is truly a complex physical oceanographic problem. It seems that refinement of the modeling approach to estimating impacts is needed.

Emerging from these studies is also that more sampling effort may be required for determining possible entrainment impacts. The study of King Harbor reveals that baseline population data may need to be collected more frequently in order to separate the potential effects of OTC from the effects of environmental variability. Pondella and colleagues recommend a 3-year interval for the collection of said data. Further, the modeling approach taken by Raimondi suggests that sample size sufficiency will be important for precisely estimating possible impacts and for determining the mitigation that might be needed. While money might be saved by a reduction in sample effort, the models suggest that any savings will be countered by increased costs associated with a possible overestimate of the mitigation required for said impact.

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11.0 Glossary

AEL	Adult Equivalent Loss
APF	Area of Production Forgone
BF	Batch Fecundity
BPJ	Best Professional Judgment
BTA	Best Technology Available
CalCOFI	California Cooperative Oceanic and Fisheries Investigations
CEQA	California Environmental Quality Act
CFD	Computational Fluid Dynamics
COI	Cytochrome c oxidase subunit 1
CSU	California State University
CWIS	Cooling Water Intake Structure
DASPEI	2-(4-(dimethylamino)styryl)-N-ethylpyridinium iodide
DNA	Deoxyribonucleic Acid
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
ET or ETM	Empirical Transport or Empirical Transport Model
FH	Fecundity Hindcasting
fps	feet per second
HPF	Habitat Production Forgone
Hz	Hertz (cycles per second)
MLML	Moss Landing Marine Laboratories
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OTC	Once-through Cooling
PCR	Polymerase Chain Reaction
PIER	Public Interest Energy Research

PM	Proportional Mortality
QPCR	Quantitative Polymerase Chain Reaction
RFP	Request for Proposals
rRNA	Ribosomal Ribonucleic Acid
RWQCB	Regional Water Quality Control Board
SL	Standard Length
SWB	Source Water Body
SWRCB	State Water Resources Control Board
SYBR	a fluorescing cyanine dye used to stain nucleic acids
USEPA	United States Environmental Protection Agency
WISER	Water Intake Structure Environmental Research